



The within-person association between alcohol use and sleep duration and quality in situ: An experience sampling study



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HIGHLIGHTS

- Alcohol use days were associated with decreased sleep quality.
- Greater alcohol use throughout the study was associated with decreased sleep quality.
- Sleep duration did not differ between alcohol use and non-alcohol use days.

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ABSTRACT

Objective: Despite evidence for detrimental effects of alcohol on sleep quality in laboratory studies, alcohol is commonly used as a self-prescribed sleep aid. This study examined the within-person associations of alcohol use with sleep duration and quality in everyday life to gain insight into the ecological validity of laboratory findings on the association between sleep and alcohol.

Method: A sample of 150 adults (age 19–89 years) were followed for 60+ days as part of an intensive experience sampling study wherein participants provided daily reports of their alcohol use, sleep duration, and sleep quality. Within-person and between-person associations of daily sleep duration and quality with alcohol use were examined using multilevel models.

Results: A significant, negative within-person association was observed between sleep quality and alcohol use. Sleep quality was lower on nights following alcohol use. Sleep duration did not vary as a function of within-person variation in alcohol use.

Conclusions: In line with laboratory assessments, alcohol use was associated with low sleep quality but was not associated with sleep duration, suggesting that laboratory findings generalize to everyday life. This examination of individuals' daily lives suggests that alcohol does not systematically improve sleep quality or duration in real life.

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1. Introduction

Despite the use of alcohol as a self-prescribed sleep aid (Johnson, Roehrs, Roth, & Breslau, 1998; Taylor & Bramoweth, 2010), alcohol may disrupt sleep. Laboratory examinations of the effects of alcohol on humans' sleep suggest that alcohol may act as a sedative early in the night, reducing both sleep-onset latency (Rundell, Lester, Griffiths, &

Williams, 1972) and number of awakenings after sleep onset (Feige et al., 2006). However, later in the night, alcohol appears to disrupt sleep, canceling out the initial benefits (for review see Ebrahim, Shapiro, Williams, & Fenwick, 2013). The purpose of the present study is to investigate the ecological validity of laboratory findings by examining whether there is evidence of a within-person association between alcohol use and sleep duration and quality in situ during daily life.

1.1. Laboratory assessments of the effect of alcohol on sleep

The most consistent findings across laboratory studies are that alcohol shortens sleep-onset latency (Williams, MacLean, & Cairns, 1983;

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Rundell et al., 1972), but does not generally affect total sleep time (MacLean & Cairns, 1982; Yules, Freedman, & Chandler, 1966; although see Arnedt et al., 2011 for exception observed in women only). As well, participants subjectively characterize their sleep as being of poorer quality and more superficial after consuming alcohol compared to placebo (Landolt, Roth, Dijk, & Borbely, 1996; Rohsenow et al., 2010). These differences in subjective sleep quality reflect objective differences in sleep efficiency (percentage of time in bed spent asleep) and depth of sleep (Keklund & Akerstedt, 1997). In particular, alcohol consumption decreases the proportion of total sleep-time spent in rapid eye movement (REM) sleep and increases the proportion of time spent in Stage 1 (light non-REM) sleep (Sagawa et al., 2011; Van Reen, Jenni, & Carskadon, 2006). Examined in parcels of time roughly corresponding to when the body is metabolizing alcohol (first half of night) and eliminating alcohol (second half of night), increases in amount of Stage 3 (deep non-REM) sleep in the first 3 h of sleep-time are accompanied by decreases in Stage 3 sleep later in the night (Stone, 1980; Williams et al., 1983).

Of note, the amount of alcohol consumed is linearly related to the extent of decrease in sleep-onset latency and the extent of increase in Stage 3 (deep non-REM) during the first 3 h of sleep (Roehrs, Buruvali, Bonahoom, Drake, & Roth, 2003; Williams et al., 1983), but not related to total sleep time (duration). The more alcohol consumed, the greater the early night increase in Stage 3 (deep non-REM) and corresponding decrease in late night Stage 3 sleep (MacLean & Cairns, 1982; Williams et al., 1983). The shift to a lighter sleep during the second half of the sleep period, as well as more awakenings (Landolt et al., 1996), may partially explain why participants perceive their sleep as being of poorer quality after alcohol consumption. Indeed, sleep efficiency during the second and third quarters of the night are the main drivers of subjective sleep quality (Rosipal, Lewandowski, & Dorffner, 2013). In sum, laboratory studies suggest that when individuals drink alcohol they are likely to experience poorer quality but not shorter sleep, and as alcohol consumption increases their sleep quality worsens.

1.2. Sleep outside of the laboratory

Although laboratory studies have increased our understanding of the associations between alcohol consumption and sleep quality, it is unclear whether the processes observed in the laboratory generalize to real-world settings (Mitchell, 2012). In situ intensive repeated measures study designs can examine whether the laboratory-based findings generalize into the real world (e.g., Larson & Csikszentmihalyi, 1983; Shiffman, Stone, & Hufford, 2008). These study designs collect intensive repeated measures data in everyday settings, as participants go about their lives. The proximal (in place and time) nature of the measurement provides for ecological validity while also reducing retrospective biases often introduced in questionnaires that ask participants to recall and aggregate information about longer periods of time (e.g., previous 30 days; Schwarz, 2007). Further, intensive repeated measures allow for the separation of between-person and within-person associations among predictor and outcome variables (Ram & Gerstorf, 2009). Repeated measures data simultaneously contain information about between-person and within-person differences (Raudenbush & Bryk, 2002). To avoid confounding between- and within-person sources of variability, between- and within-person effects must be disaggregated (see Curran & Bauer, 2011).

Few studies to date have used in situ designs to examine associations between alcohol and sleep. Galambos, Dalton, and Maggs (2009), using 14-days of data provided by 191 Canadian undergraduate students (age 17 to 19 years), found that self-reported sleep quality was lower on alcohol use days than on no alcohol use days. Self-reported sleep duration was shorter on alcohol use days than on no alcohol use days. Similarly, Geoghegan, O'Donovan, and Lawlor (2012), in a 7-day study of 47 Irish college students (age 20 to 25 years) found that sleep-onset latency and sleep duration were shorter on alcohol use days than on no-

alcohol use days, but did not find any differences in self-reported reported sleep quality. Patrick, Griffin, Huntley, and Maggs (2016), in a 56-day study of 667 U.S. college students, and the only study to separate within- and between-associations between alcohol and sleep, found that sleep quality was lower and sleep quantity was shorter after binge drinking, defined as 4+/5+ drinks in a 2-hour period for women/men. These existing studies have not consistently replicated laboratory results and the discrepancy may stem at least partially from the use of college student samples given findings that greater alcohol use is associated with later sleep schedules in student populations (Singleton & Wolfson, 2009).

1.3. The present study

To bridge laboratory and existing in situ studies, the present study used a U.S. sample of adults who were observed for many (60+) days. To reflect laboratory studies (e.g., Roehrs et al., 2003; Williams et al., 1983), the present study considered day-to-day differences in alcohol dose, hypothesizing that alcohol use would have a negative, linear relationship with sleep quality, but not with sleep duration.

2. Method

2.1. Participants

The Intraindividual Study of Affect, Health, and Interpersonal Behavior (iSAHIB; Ram et al., 2014) worked with 150 adults (51% women) recruited from the Pennsylvania State University and surrounding community, and purposively stratified by gender and across the adult life span in 18–24 ($n = 22$), 25–34 ($n = 27$), 35–49 ($n = 30$), 50–64 ($n = 41$), 65+ ($n = 30$) year age-bins. Participants were between 19 and 89 years of age ($M = 47.10$, $SD = 18.76$), had obtained between 2 and 24 years of formal education ($M = 16.36$, $SD = 3.90$), and had between 0 and 6 children ($M = 1.5$, $SD = 1.41$). Participants self-identified as White (91%), African American (4%), Asian American (1%), and Mixed or Other (4%) ethnicity, and had yearly family income ranging from 'under \$ 20,000' to '\$ 200,000 and over' ($Median = \$ 50,000$ – $\$ 74,999$), with 8.7% declining to answer. Of the 150 participants, 136 (90.7%) completed the entire protocol, and 14 withdrew (relocation, health, loss of interest) after completing between a third ($n = 11$, 7.3%) and two-thirds ($n = 3$; 2.0%) of the total protocol. Participants who withdrew did not differ systematically from those who completed the entire protocol with respect to the measured demographics ($ps > 0.05$). For the present analysis, tethered sleep and alcohol data span 8381 days (93.1% of possible days) nested within 150 persons.

2.2. Procedure

After being recruited, learning about the intensive nature of the assessments, and self-selecting into the study, participants completed a series of three 21-day "measurement bursts" spaced at approximately 4.5-month intervals ($M = 5.25$ months between bursts 1 and 2; 4.25 months between bursts 2 and 3). During each burst, individuals reported about their social interactions as they went about their daily lives, and provided end-of-day reports about their feelings, thoughts, and behaviors using a study-provided smartphone (Verizon XV6900). Prior to and after each 21-day burst, individuals visited the laboratory to receive training or debriefing and complete web-based batteries of questionnaires. Participants were compensated \$500 for completing the entire protocol.

2.3. Measures

2.3.1. Daily sleep

Daily sleep was measured at the end of each day using items from The Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds

Berman, & Kupfer, 1989). Typically used as a previous-month recall measure, two items were configured for daily assessment as previous-night recalls. *Sleep duration* was measured as responses to the question, "How many hours of sleep did you get last night (This may be different from # of hours spent in bed)? Please round to the nearest hour." *Sleep quality* was measured as responses to the question, "Last night, how would you rate your quality of sleep?" on a touch point continuum (slider-type interface) with anchors at 0 = Very Bad and 100 = Very Good (numbers not visible to participants). Such single-item, daily self-report measures are more strongly correlated with actigraphy based measures of sleep than retrospective, previous month reports (Lauderdale, Knutson, Yan, Liu, & Rathouz, 2008), are practical when measurements are taken frequently to reduce participant burden, and have demonstrated favorable psychometric properties (e.g., Cappelleri et al., 2009). On average, participants slept 6.78 h per night ($SD = 1.52$, Range = 0 to 14) with quality of 65.72 ($SD = 21.50$, Range = 0 to 100).

2.3.2. Day's alcohol consumption

Each day's alcohol consumption was measured at the end of the day using three items of the form, "How many of the following did you consume today?" followed with prompts and definitions of standard servings for "beer" (12 fl oz), "wine" (5 fl oz), and "shots of liquor" (1.5 fl oz). Responses given on a 0, 1, 2, 3, 4, 5+ response scale for each beverage category were summed to obtain the total servings of alcohol consumed for each day (see Conroy et al., 2015 for other analyses of these alcohol data). On average, participants consumed 0.67 drinks per day ($SD = 1.33$; range = 0 to 12). On drinking days (29.67% of all days and with 86% of participants having at least one drinking day), participants drank an average of 2.24 drinks ($SD = 1.55$; range = 1 to 12). To reduce potential outlier effects, days with >5 total drinks consumed (1.63% of days) were recoded as 5+.

2.3.3. Covariates

Participants reported each day's caffeine use by indicating the number of caffeinated drinks (0, 1, 2, 3, 4, 5+) they consumed (with instructions for reporting relative to caffeine in a standard cup of coffee). *Day of week* was derived from the date of response and, following previous literature (e.g., Galambos et al., 2009), split into three categories: *Friday & Saturday*, *Sunday*, and *other weekdays* (reference category). *Gender* and *age* were obtained from a demographics questionnaire.

2.4. Data analysis

The intensive repeated measures data (8381 days nested within 150 persons) were analyzed using multilevel models (Snijders & Bosker, 2012) that were parameterized to separate within-person and between-person associations by splitting predictors into time-invariant (between-person) and time-varying (within-person) components (see Bolger & Laurenceau, 2013). Time-invariant person-level variables for *usual alcohol use*, *usual caffeine use*, *usual sleep quality*, and *usual sleep duration* were calculated as the arithmetic mean across each individual's repeated measures. Time-varying, day-level variables are typically calculated as deviations from those person-level means. However, to facilitate interpretation of the intercept as *sleep duration* or *sleep quality* on a typical, no alcohol use weekday and to facilitate interpretation of the association between day's alcohol use and sleep as differences from zero to one drink, the *day's alcohol use* variable retained a 0 (no alcohol use) to 5+ (highest level of alcohol consumption) coding (see Patrick et al., 2016 for a similar centering approach in the context of binge drinking in college students, and Enders & Tofighi, 2007 for a discussion of centering predictor variables in the case of non-normally distributed Level 1 predictor variables); *day's caffeine use*, *previous day's sleep quality*, and *previous day's sleep duration* were calculated as daily deviations from person-specific means; *day of week* was dummy coded such that 0 represented Monday to Thursday; and *age* and *gender* were sample-mean centered.

Models were constructed as

$$\begin{aligned} Sleep_{it} = & \beta_{0i} + \beta_{1i}Day'sAlcoholUse_{it} + \beta_{2i}Friday\&Saturday_{it} \\ & + \beta_{3i}Sunday_{it} + \beta_{4i}Day'sCaffeineUse_{it} \\ & + \beta_{5i}PreviousDay'sSleepQuality_{it} \\ & + \beta_{6i}PreviousDay'sSleepDuration_{it} + e_{it} \end{aligned} \quad (1)$$

where $Sleep_{it}$ is the sleep variable of interest (sleep duration and quality were examined separately) for person i on day t ; β_{0i} indicates the expected sleep duration or quality on a weekday with no alcohol use and typical caffeine use; β_{1i} indicates within-person differences in sleep associated with the differences in day's alcohol use; β_{2i} and β_{3i} indicate differences in sleep associated with Friday and Saturday and with Sunday relative to other days of the week (Monday through Thursday), respectively; β_{4i} indicates differences in sleep associated with the day's caffeine use; β_{5i} and β_{6i} indicate differences in sleep associated with the previous day's sleep quality and duration, respectively, and e_{it} are day-specific residuals that were allowed to autocorrelate (AR1).

Person-specific intercepts and associations (from the Level 1 model) were specified (at Level 2) as

$$\begin{aligned} \beta_{0i} = & \gamma_{00} + \gamma_{01}UsualAlcoholUse_i + \gamma_{02}UsualCaffeineUse_i + \gamma_{03}Age_i + \gamma_{04}Gender_i \\ & + \gamma_{05}UsualSleepDurationorQuality_i + u_{0i} \\ \beta_{1i} = & \gamma_{10} + \gamma_{11}UsualAlcoholUse_i + \gamma_{12}UsualCaffeineUse_i + \gamma_{13}Age_i + \gamma_{14}Gender_i \\ & + \gamma_{15}UsualSleepDurationorQuality_i + u_{1i} \\ \beta_{2i} = & \gamma_{20} \\ & \dots \\ \beta_{6i} = & \gamma_{60} \end{aligned} \quad (2)$$

where the γ s are sample-level parameters and the u s are residual between-person differences that may be correlated, but are uncorrelated with e_{it} . Parameters γ_{11} through γ_{15} indicate how between-person differences in the within-person associations of day's alcohol use and sleep were moderated by usual alcohol use, usual caffeine use, usual sleep duration or quality (with usual sleep duration included in the sleep quality model and usual sleep quality included in the sleep duration model), age, and gender. Quadratic and cubic age and other interaction terms (e.g., day's caffeine use \times Usual caffeine use) were also tested but were not significant and thus not included in the more parsimonious final models.

All models were fit using the nlme package in R (Pinheiro, Bates, DebRoy, Sarkar, & Core Team, 2015) using maximum likelihood estimation, with incomplete data (<1%) treated using missing at random assumptions. Statistical significance was evaluated at $\alpha = 0.05$.

3. Results

3.1. Associations between alcohol use and sleep duration

Results from the multilevel model examining associations between alcohol use and sleep duration are shown in the left columns of Table 1. In line with the hypothesis that the day's alcohol use would not affect sleep duration, the within-person association between *sleep duration* and *day's alcohol use* was not significant ($\gamma_{10} = -0.02$, $p = 0.32$). This within-person association was not moderated by individuals' *usual alcohol use*, *usual caffeine use*, *usual sleep quality*, *age*, or *gender* (γ_{11} to γ_{15} , $ps > 0.05$). The between-person association between *sleep duration* and *usual alcohol use* was positive and significant ($\gamma_{01} = 0.33$, $p < 0.001$). That is, participants who drank more during the course of the study tended to sleep for longer.

Looking at the covariates, we found the expected effects of *day's caffeine use*. On days that participants consumed more caffeine than usual, they slept less ($\gamma_{40} = -0.08$, $p < 0.001$). However, there was no evidence of a between-person association. Individual differences in *usual caffeine use* were not related to *sleep duration* ($\gamma_{02} = 0.02$, $p = 0.65$). Relative to weekdays, individuals' *sleep duration* was significantly longer on *Friday & Saturday* ($\gamma_{20} = 0.36$, $p < 0.001$) and *Sunday nights* ($\gamma_{30} = 0.24$, $p < 0.001$).

Table 1
Results of multilevel models examining associations between alcohol use and sleep duration and quality.

Fixed effects	Sleep duration			Sleep quality		
	Est.	SE	p-value	Est.	SE	p-value
Intercept (γ_{00})	6.67*	0.06	<0.001	64.81*	1.00	<0.001
Day's alcohol use (γ_{10})	-0.02	0.02	0.32	-0.71*	0.32	0.03
Friday/Saturday (γ_{20})	0.36*	0.04	<0.001	1.83*	0.47	<0.001
Sunday (γ_{30})	0.12*	0.04	0.004	1.13*	0.51	0.03
Day's caffeine use (γ_{40})	-0.08*	0.02	<0.001	-0.75*	0.23	0.001
Previous day's sleep quality (γ_{50})	0.001	0.001	0.51	-0.23*	0.01	<0.001
Previous day's sleep duration (γ_{60})	-0.22*	0.01	<0.001	-0.04	0.15	0.77
Usual alcohol use (γ_{01})	0.33*	0.08	<0.001	-3.06*	1.36	0.03
Usual caffeine use (γ_{02})	0.02	0.05	0.65	-1.06	0.87	0.23
Age (γ_{03})	-0.01	0.003	0.12	0.11*	0.05	0.04
Gender (γ_{04})	-0.10	0.12	0.41	2.85	2.00	0.16
Usual sleep duration/quality (γ_{05})	0.03*	0.005	<0.001	7.50*	1.25	<0.001
Day's alcohol use \times usual alcohol use (γ_{11})	-0.01	0.02	0.91	0.44	0.33	0.18
Day's alcohol use \times usual caffeine use (γ_{12})	-0.01	0.02	0.69	-0.0001	0.26	0.99
Day's alcohol use \times age (γ_{13})	-0.001	0.001	0.47	-0.002	0.02	0.87
Day's alcohol use \times gender (γ_{14})	-0.01	0.04	0.76	-0.004	0.55	0.99
Day's alcohol use \times usual sleep duration/quality (γ_{15})	0.002	0.002	0.24	-0.11	0.34	0.74
Random effects	Est.	CI		Est.	CI	
Intercept ($\sigma_{u_0}^2$)	0.65	0.57–0.75		11.14	9.76–12.72	
Day's alcohol use ($\sigma_{u_1}^2$)	0.10	0.06–0.16		1.65	1.15–2.36	
Correlation ($r_{u_{01}}$)	0.11	-0.11–0.32		-0.10	-0.34–0.15	
AR(1)	0.35	0.32–0.39		0.44	0.41–0.50	
Residual (σ_e^2)	1.37	1.34–1.40		18.72	18.28–19.17	
Fit Indices						
AIC	28,433.83			71,520.80		
BIC	28,588.52			71,675.49		

Note: $N_{observations} = 8381$ days nested within 150 persons; AIC = Akaike information criteria; BIC = Bayesian information criteria; SE = standard error; CI = confidence intervals.

* $p < 0.05$.

0.12, $p < 0.01$), relative to other days of the week. *Previous day's sleep duration* ($\gamma_{60} = -0.22$, $p < 0.001$), but not *previous day's sleep quality* ($\gamma_{50} = 0.001$, $p = 0.51$), was negatively associated with *sleep duration*. As would be expected, higher *usual sleep quality* was associated with longer *sleep duration* ($\gamma_{05} = 0.03$, $p < 0.001$). However, neither *age* nor *gender* were significantly related to *sleep duration* ($ps > 0.05$).

3.2. Associations between alcohol use and sleep quality

Results from the multilevel model examining associations between alcohol use and sleep quality are shown in the right columns of Table 1. In line with the hypothesis that alcohol use reduces sleep quality, we found a significant, negative within-person association between *sleep quality* and *day's alcohol use* ($\gamma_{10} = -0.71$, $p = 0.03$). Shown for the prototypical individual by the dashed black line in Fig. 1, each additional drink was associated with a 0.71 decrease in *sleep quality*. Although a relatively small effect on average with an effect size of 0.16 (estimate for the within-person association divided by the within-person residual standard deviation, $\gamma_{10}/\sigma_e = 0.71/\sqrt{18.72}$), this within-person association ranged widely, from $\beta_{1i} = -3.75$ to 1.91 across persons (thin gray lines). Notably, the extent of the within-person association was not related to individuals' *usual alcohol use*, *usual caffeine use*, *usual sleep duration*, *age*, or *gender* ($ps > 0.05$). The between-person association between *usual alcohol use* and *sleep quality* was negative and significant ($\gamma_{01} = -3.06$, $p = 0.03$). That is, participants who drank more alcohol during the study tended to have lower overall sleep quality.

Looking at the covariates, we found the expected association between *day's caffeine use* and *sleep quality* ($\gamma_{40} = -0.75$, $p < 0.01$). That is, on days that participants consumed more caffeine than usual, they reported lower quality sleep. However, there was no between-person association; *usual caffeine use* was not related to *sleep quality* ($\gamma_{02} = -1.06$, $p = 0.23$). Consistent with duration, *sleep quality* was significantly higher on *Friday & Saturday* ($\gamma_{20} = 1.82$, $p < 0.001$) and *Sunday nights* ($\gamma_{30} = 1.13$, $p = 0.03$), relative to other days of the week. As expected, *previous day's sleep quality* was associated with *sleep quality* ($\gamma_{05} = -0.23$, $p < 0.001$), and although *previous day's sleep duration* was not related to current sleep quality, ($\gamma_{06} = -0.04$, $p = 0.77$), individuals with

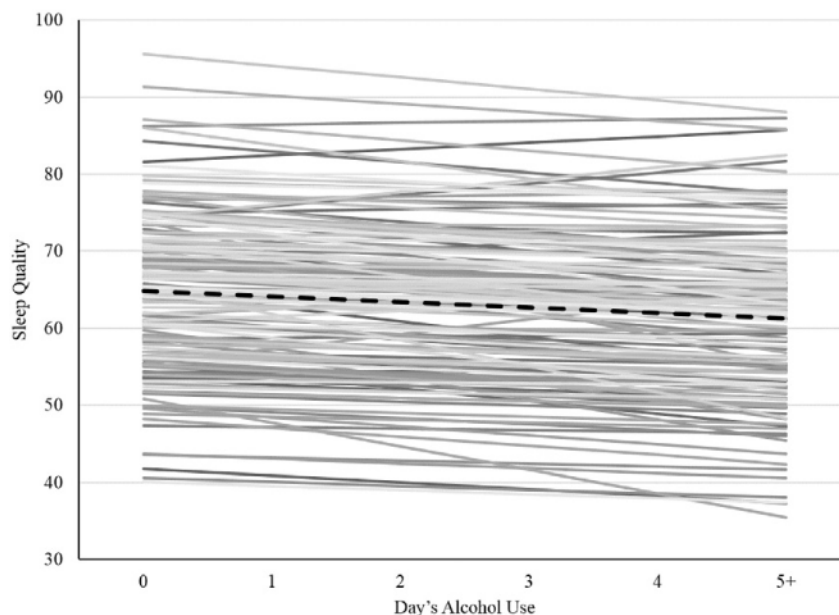


Fig. 1. Prototypical within-person (dashed black line, $\gamma_{10} = -0.71$, $p < 0.05$) and person-specific (thin lines; $N = 150$; $\beta_{1i} = -3.75$ to 1.91) associations between daily sleep quality (100 ratings) and the day's alcohol use (0 to 5+ drinks).

higher usual sleep duration tended to have higher overall sleep quality ($\gamma_{05} = 7.50, p < 0.001$) As in prior studies, higher age was associated with higher overall sleep quality ($\gamma_{13} = 0.11, p = 0.04$), and gender was not related to overall sleep quality ($\gamma_{04} = 2.85, p = 0.16$).

4. Discussion

4.1. Within-person effects of alcohol on sleep

The present study demonstrated that the within-person association between alcohol use and sleep quality observed in the laboratory extends to daily life. We observed a negative within-person association between alcohol use and sleep quality. On days with greater alcohol use, sleep quality was lower, consistent with laboratory research demonstrating a dose-related association between alcohol use and sleep disturbance (e.g., Landolt et al., 1996; MacLean & Cairns, 1982). Even though small, it is notable that this association can be detected in the real world in the midst of all the noise that exists outside the laboratory. Sleep duration was not associated with alcohol use. This is also consistent with laboratory findings demonstrating that alcohol use impacts the distribution of sleep stages but not sleep duration (e.g., Williams et al., 1983). The finding for sleep duration is inconsistent with previous in situ studies that observed shorter sleep duration following alcohol (e.g., Galambos et al., 2009) but all existing in situ studies used college samples, only one separated between- and within-person associations (Patrick et al., 2016), and none tested for a linear association between increasing amounts of alcoholic drinks (focusing instead on dichotomized alcohol vs. no alcohol use days or binge drinking vs no binge drinking days) and sleep parameters.

4.2. Between-person associations of alcohol use and sleep

While not the focus of the current study, individuals with higher levels of usual alcohol use tended to have longer average sleep duration. This between-person association is unlikely to be driven by the acute effects of alcohol. It is perhaps more likely that participants exhibiting greater rates of alcohol use had greater capacity to extend sleep duration throughout the study due to fewer time use obligations. Consistent with this interpretation, level of usual alcohol use was negatively correlated with participants' reports of average time spent at work ($r = -0.24, p < 0.01$). In line with cross-sectional survey studies (e.g., Popovici & French, 2013), individuals with higher levels of usual alcohol use tending to report lower sleep quality.

4.3. Associations between sleep and covariates

Other findings of interest include that caffeine use was negatively associated with sleep duration and quality, in line with previous laboratory research noting that the effects of caffeine include reductions in total sleep time and perceived sleep quality (Hindmarch et al., 2000). The inclusion of caffeine adds to the ecological validity of the current study given the common practice of consuming caffeinated drinks to promote wakefulness and to enhance the experience of alcohol intoxication (Ishak, Ugochukwu, Bagot, Khalili, & Zaky, 2012). Also in line with previous findings (Hale, 2005), greater sleep duration and quality was observed on Friday and Saturday and Sunday nights relative to week nights.

Sleep quality was positively associated with age and sleep duration was not linearly associated with age. While sleep duration and quality have been reported to decline with age across adulthood (Floyd, Janisse, Jenuwine, & Ager, 2007), robust associations have not consistently been observed (Reyner, Horne, & Reyner, 1995) and may depend on sampling factors such as the health status of study participants (Bliwise, 1993). Indeed, recent studies controlling for health factors have observed increases in sleep quality across adulthood into old age

(Grander et al., 2012; Luca et al., 2016). Consistent with some existing experience sampling studies (e.g., Galambos et al., 2009) but not others (Patrick et al., 2016), no gender effects were observed in the present study.

4.4. Limitations and outlook

It is important to consider the findings in light of the study's limitations. The sample was drawn from a mostly White population in central Pennsylvania with moderate and low-risk alcohol use. As such, care should be taken when attempting to generalize the findings to more diverse, and/or high risk, heavy alcohol use populations. This study sample is unique in that it includes adults between ages 18 and 89 years and allowed, with 60+ days of reporting, for assessment of the naturally-occurring variation and co-variation of a fluctuating behavior (alcohol use).

Future in situ studies may be improved through collection of more refined sleep data, either by more fine-grained self-report (e.g., 15 min increments) or actigraphy-based, objective measures of sleep duration, especially when these devices can provide information on sleep onset latency (which is more difficult to obtain through self-report). Similarly, more precise data on how much alcohol individuals are ingesting (e.g., using response scales that do not include a 5+ ceiling) and when they start and stop drinking will allow greater consideration of the biological processes through which alcohol effects sleep and examination of time course on which different dosages of alcohol influence sleep (e.g., Leffingwell et al., 2014; Roehrs & Roth, 2001; Thakkar, Sharma, & Sahota, 2015). Theories of alcohol's sleep disrupting effects are associated with the elimination of alcohol within 4 to 5 h of sleep onset. In particular, alcohol may exert stimulating effects when blood alcohol concentration is rising but sedative effects when blood alcohol concentration peaks and begins to decline (see Hendler, Ramchandani, Gilman, & Hommer, 2013 for review). Thus, it may be especially important to track timing of both ingestion of alcohol and other foods and beverages (e.g., those containing caffeine) that change the concentration of alcohol. In terms of the measure of caffeine intake, a standard definition of the amount of caffeine intake may be preferable in future studies rather than using number of caffeinated drinks as in the present study as caffeine content may differ across drink types (Heckman, Weil, Mejia, & Gonzalez, 2010).

4.5. Synopsis

In summary, the current study extends previous in situ examinations of the association between sleep and alcohol using an adult sample that was observed for many days, and by considering how day-to-day differences in alcohol dose were linked to sleep duration and quality. The current study demonstrated that the within-person coupling between alcohol use and sleep quality observed in the laboratory can also be found in the real world using intensive measurements of daily life. Although often used as a self-prescribed sleep aid, our examination of individuals' daily lives provides confirmation that alcohol does not systematically improve sleep quality or duration in real life. As such, multi-component prevention programs (e.g., Thadani, Hutching, & LaBrie, 2014) aiming to promote responsible alcohol use may benefit from addressing knowledge deficits about alcohol's effects on sleep quality and duration.

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Contributions

DEC, ALP, and NR designed the original study and oversaw data collection. DML, JLM, NR aided in the interpretation of the data. DML and NR performed the statistical analyses. All authors contributed to writing of and approved the final manuscript.

Conflict of interest

The authors declare that they have no conflicts of interest.

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